# Clean up your oil and keep it clean!

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Contaminated oil kills machines. Clean oil is one of the most important factors affecting the service life of the lubricated components of all machinery[1]. In hydraulic systems, clean fluid is absolutely essential for successful long-term operation. Although machines equipped with rolling element bearings are especially sensitive to particulate contamination, machines using fluid-film bearings are not immune to such damage. Many sources cite dramatic improvements in expected machine life resulting from even modest improvements in lubricant cleanliness.

This all sounds reasonable, and smacks of common sense. Closer scrutiny reveals a few questions:

- How is oil cleanliness quantified?
- How clean is "new" oil?
- How clean does your oil need to be?
- What improvements in machine life can you expect from cleaning up your oil?
- What about other types of contamination?
- What steps can you take to clean up your oil?

Let's look at these issues one at a time.

## How is oil cleanliness quantified?

ISO 4406 establishes the relationship between particle counts and cleanliness in hydraulic fluids (common practice has extended the application of the standard to lubricants). This international standard uses a code system to quantify contaminant levels by particle size in micrometers (µm). Using ISO 4406, a machine owner/operator can set simple limits for excessive contamination levels, based on quantifiable cleanliness measurements.

Table 1 illustrates the ISO 4406 cleanliness codes[2]. This standard allows you to quantify current particulate cleanliness levels and set targets for cleanup. The current standard provides a 3-part code to represent the number of particles per milliliter (mL) of fluid greater than 2 µm, 5 µm, and 15 µm, respectively[3]. Many labs will report either a 2-part code, or a 3-part code, as specified by the user. The 2-part code refers to particle counts in the 5 µm and 15 µm size ranges. A 3-part code of **17/14/12** would indicate 640 to 1,300 particles/mL greater than or equal to 2 µm, 80 to 160 particles/mL greater than or equal to 5 µm, and 20 to 40 particles/mL greater than or equal to 15 µm. See Table 1 and Figure 1.

| ISO Code | Minimum | Maximum |
|---|---|---|
| • | • | • |
| • | • | • |
| • | • | • |
| **10** | 5 | 10 |
| **11** | 10 | 20 |
| **12** | 20 | 40 |
| **13** | 40 | 80 |
| **14** | 80 | 160 |
| **15** | 160 | 320 |
| **16** | 320 | 640 |
| **17** | 640 | 1300 |
| **18** | 1300 | 2500 |
| **19** | 2500 | 5000 |
| **20** | 5000 | 10000 |
| **21** | 10000 | 20000 |
| **22** | 20000 | 40000 |
| **23** | 40000 | 80000 |
| • | • | • |
| • | • | • |

**Table 1. ISO 4406 fluid cleanliness codes (particles per mL).**

[1] For the purposes of this article, and in keeping with common industry practice, the terms "clean" and "cleanliness" refer to the amount and size of particulate contamination in a lubricating or hydraulic fluid.

[2] The ISO standard calls the codes "scale numbers." You may also find them referred to as "range numbers" and represented as $R_5/R_{15}$ for 2-part codes and $R_2/R_5/R_{15}$ for 3-part codes.

[3] The current standard is ISO 4406:1987(E). The ISO is now circulating a draft proposal, ISO/DFIS 4406:1999(E), for contamination levels measured with automatic particle counters calibrated in accordance with ISO 11171. In the proposed standard, the three parts signify the number of particles/mL greater than 4 µm, 6 µm, and 14 µm, respectively (scale or range numbers $R_4/R_6/R_{14}$).

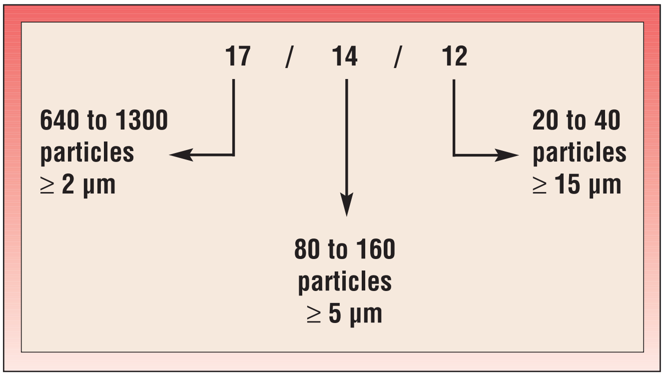


**Figure 1. ISO code example.**

Notice each step in the ISO code represents either double or half the particle count relative to an adjacent code. It is important to note the "/" character in the written form of the code is merely a separator, and does not signify a ratio of the scale numbers.

## How clean is "new" oil?

Studies of "new" turbine oils, crankcase oils, hydraulic fluids, and bearing oils delivered to customers indicate varying degrees of cleanliness, with ISO codes from a low of **14/11**, to as high as **23/20**. Drum-delivered products were generally found to be cleaner than bulk-delivered products. Referring to Table 1, you might think twice before putting "new" oil with an ISO **23/20** measurement in your machine. Improper storage procedures can contribute additional contamination to new oil. Poor handling practices are another source of new oil contamination. (Do you know what types of vessels are used in your plant for transporting and adding makeup oil? Are they as clean as you want your oil to be?) After implementing cleanup programs, many users find the dirtiest oil in their plant is incoming "new" oil. It is clear that proper filtering of new oil during or before filling is a prudent and highly desirable practice to extend machine life.

## How clean does your oil need to be?

Each machine class should be evaluated for cleanliness levels appropriate to the application. In general, machines with tight clearances and/or anti-friction (rolling element) bearings benefit greatly from very clean oil. Turbine electro-hydraulic control (EHC) systems and many aeroderivative gas turbines are examples of industrial machines that require extremely clean oil for proper performance and long life. Filter systems rated to remove particles as small as 3 µm to 7 µm are commonly used in such applications. Hydraulic systems' targets should also be adjusted to cleaner levels for higher system operating pressures. (See related article, "Lubrication – A strategic part of asset management" on page 6.)

Table 2 presents some typical base lubricating oil cleanliness targets for common machines and machine elements. Like most guidelines, these targets are suggested as starting points. You will probably make adjustments to these levels as you learn how your machines respond to cleaner lubricants.

| Machine / element | ISO Target |
|---|---|
| Roller bearing | **16/14/12** |
| Journal bearing | **17/15/12** |
| Industrial gearbox | **17/15/12** |
| Mobile gearbox | **17/16/13** |
| Diesel engine | **17/16/13** |
| Steam turbine | **18/15/12** |
| Paper machine | **19/16/13** |

**Table 2. Typical base cleanliness targets.**

## What improvements in machine life can you expect from cleaning up your oil?

While it may feel good to know you have clean oil in your machines, how good can you afford to feel? The answer to this question depends to some degree on the specific machine application. However, studies performed in many industries all show dramatic extensions in expected machinery life by improving lubricant cleanliness. In one example, a reduction of particles larger than 10 µm from 1000/mL to 100/mL resulted in a 5-fold increase in machine life… an attractive return on your cleanup investment. An additional benefit of cleaner oil is a lower noise floor for wear particle detection measurements. It's much easier to detect subtle changes in the amount of wear debris in a clean system than in a dirty one.

Society of Automotive Engineers (SAE) studies have shown engine wear reductions of 50% when filtering crankcase oil to 30 µm, and 70% when filtering to 15 µm, as compared with filtering to 40 µm. By implementing some of the measures outlined in this article, you will soon be able to document your own success stories.

## What about other types of contamination?

As destructive as particulate contamination can be, there are other contaminants that also contribute to oil degradation and premature machine wear. A short list of "non-particulate" contaminants includes water, coolants, fuels, and process fluids. The most common of these is water. Water alone is a significant factor in lubricant degradation. When combined with iron or copper particles, water becomes even more powerful in attacking

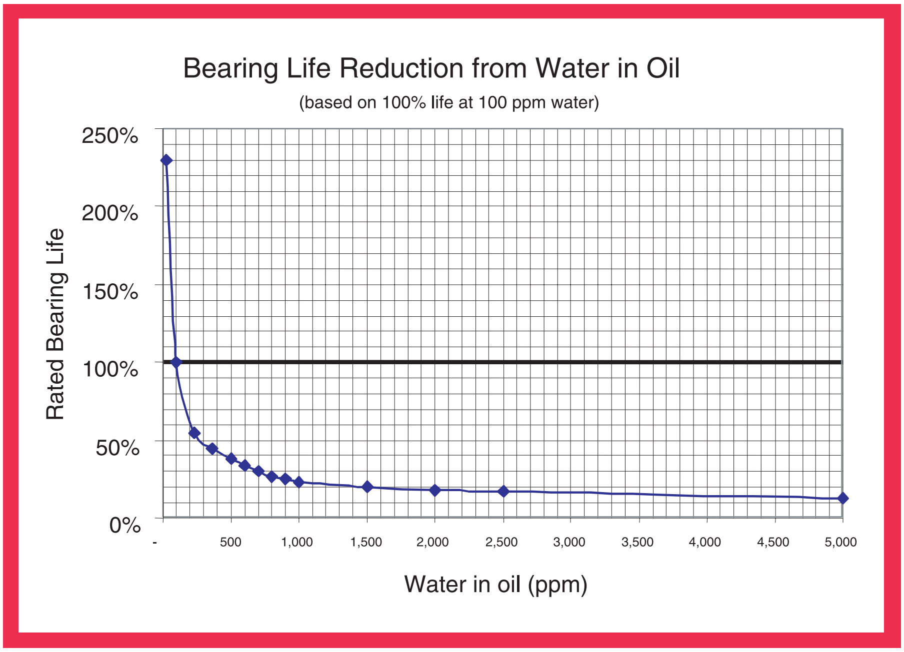


**Figure 2. Effect of water on rolling element bearing life.**

lubricant base-stocks and additives. The adverse effects of water in oil include:

- Lubricant breakdown, through oxidation and additive precipitation.
- Changes in viscosity, affecting the ability of a lubricant to maintain the film thickness necessary to protect the lubricated surfaces.
- Corrosion.
- Accelerated fatigue of lubricated surfaces.

Even very small amounts of water can be harmful in machines equipped with rolling element bearings. Typical life reduction of rolling element bearings caused by various concentrations of water in oil is depicted in Figure 2.

Lubricant film thickness in fluid-film journal bearings is substantially larger than that found in rolling element bearings, and hydrodynamic pressures are typically lower. However, the babbitt in these bearings, being composed primarily of lead and tin, is susceptible to oxidation damage from water and oxygen. Water can also reduce the load-carrying capacity of a fluid-film bearing lubricant sufficiently to cause journal-to-bearing contact (wiping). The reduction in film thickness also increases the sensitivity of fluid-film bearings to particulate contaminants.

## What steps can you take to clean up your oil?

Let's say you are now convinced that cleanup is the way to go, but you don't know how to get there. Filtration, storage, and handling procedures are the key areas to concentrate your energies. The important elements of a successful campaign to clean up your oils are:

- Measure and evaluate current cleanliness levels to establish baselines for comparison.
- Examine and evaluate your current storage and handling practices.
- Set cleanliness targets based on your goals for longer machine life and/or reduced maintenance and downtime costs.
- Evaluate, select, and implement the improvements in filtration, storage, and handling procedures required to achieve your goals.
- Measure and trend your progress. (Don't be afraid to adjust your procedures as needed to meet your targets.)
- Document the impact of your investment on availability, maintenance expense, and machine life.

With these elements delineated, some of the practical aspects of improving your filtration, storage, and handling procedures can be addressed.

## Improving filtration, storage, and handling procedures

Many improvements to your filtration, storage, and handling procedures can be made with minimal cost. A little time spent simply reviewing your current storage and handling procedures can be revealing (and in some cases, even **shocking**). Figures 3, 4, and 5 illustrate a few problems commonly seen in many operations. During the

**Figure 3. Poor handling practices – filler neck screen punched out.**

**Figure 4. Poor storage practices – loose bung (drum cap).**

**Figure 5. Poor handling practices – dirty fill pump.**

evaluation phase, it is important to identify contamination **sources** as well as the levels. Contamination sources may include:

- **Contaminated new oil.** As previously mentioned, new oil is often not as clean as you might think, usually becoming contaminated during transportation, storage, and handling.
- **Built-in contamination.** Machine components can become contaminated from handling practices encountered during overhauls or rebuilding processes. It is important to review shop procedures relating to cleanliness of internal wetted parts, hoses, and lubricant piping.
- **Ingested contamination.** Unfiltered sump vents and faulty seals are common problems which can result in contaminants (including water as well as particulates) entering the lube system from the outside environment. Minor modifications to vent systems can reap rewards in this area.
- **Internally-generated contamination.** Recirculating wear particles through machine components can create a self-fulfilling prophecy of machine destruction. Normal full-flow filtering removes some, but not all, wear particles. In fact, many full-flow filtration systems are only effective in removing particles larger than 40 µm. Concentrating on the hardest and most abrasive particles is an effective strategy for this category of contaminants.

Once the contamination sources are identified, you can concentrate on the areas most likely to generate your target cleanliness levels.

## Filtration

Offline recirculating (“kidney loop”) filtration systems can be very effective in achieving and maintaining your cleanliness targets. In some cases, a permanent installation is called for, with continuous sidestream (“bypass”) filtering. In less critical applications, where sump volumes are usually smaller, the job can often be handled with a cart-mounted portable filtration system (Figure 6). Portable cart-mounted systems can be used at scheduled intervals, or in response to increasing contamination trends in your oil analysis data. Portable systems can also be used for pre-filtering new oil before or during system charging. Cartridge-type filters are common on this type of equipment, so you can easily change to the appropriate filter element for the specific cleanliness target of each machine or machine class being serviced. Since cross-contamination is a possibility with portable systems, filter changes and adequate flushing are essential before use with a different lubricant. Maintaining separate systems for each lubricant being filtered is another solution to this potential problem.

**Figure 6. Portable filter cart.**

## Storage and Handling

Improvements to storage and handling procedures can often be implemented at low cost, relative to the benefits. Controlling temperature over a relatively narrow range is important for proper drum storage. Drums “breathe” as the internal pressure increases and decreases with temperature variations. Moisture and other contaminants are forced into the drum when the internal pressure decreases. In most climates, this problem must be addressed by storing drums in enclosed, temperature-controlled storage facilities. Shielding storage containers from dirt and moisture are other obvious measures that will keep your new oil in good condition. Be as careful with pumps and transfer containers as with your storage containers. This will minimize the chances of cross-contaminating with other lubricants and introducing contaminants into machines when topping or filling.

## Water removal

Since the sources for water contamination are so numerous and ubiquitous,

eliminating all sources of moisture can be very difficult. Removing water from oil can also be a challenging task, but there are several methods available. Each method has advantages and disadvantages, so each must be carefully evaluated for the particular application. Some of the common methods for removing water from oil, along with their tradeoffs, include:

- **Settling/Evaporation**
  - Natural – gravity acts on the water to separate it from the oil, and water escapes from the fluid via natural evaporation.
  - Inexpensive.
  - Least effective of known methods.
  - Properly-designed reservoir is required.
  - Only free water is removed.
- **Centrifuging (Centrifugal Separation)**
  - Only the free water form of water is removed to about 20 ppm by weight, above the saturation point.
  - Entrained gases aren't removed.
  - Emulsified water content tends to increase.
  - Dirt and other solids are removed.
  - Additives can be removed by this method.
- **Coalescing Filters/Screens**
  - Only free water is removed.
  - A coalescing cartridge filter is used to separate the water from the oil.
  - Additives can be removed by this method.
  - Only effective for narrow ranges of viscosity and specific gravity.
  - Some manufacturers claim "No removal of additives."
- **Filter/Dryers**
  - Cartridge-type filters that use super-absorbent materials to soak up water.
  - Dissolved water isn't removed.
- **Vacuum Treating (Vacuum Dehydrating)**
  - The wet lubricant is heated in a vacuum to separate the water.
  - Additives usually aren't removed from the lubricant, since it is a chemical separation.
  - Dissolved, emulsified, and free water can be removed.
  - When combined with effective filtration media, capable of being a highly-effective lubricant purification system.
- **Gas Sparging/Air Stripping**
  - The chemical separation principle of air stripping is used.
  - Dissolved, emulsified, and free water are removed.
  - Additives are not removed.
  - Nitrogen or air can be used.

## Purchasing clean oil

An additional cleanup step, which is often overlooked, is to specify the cleanliness levels of the lubricants you purchase. You may pay a little more up front, but the savings in machine availability, filtration costs, and machine life extension often more than offset the additional cost. If you choose this route, be sure to test the incoming oil to verify you get what you paid for.

## Conclusion

It's best not to take administration of your oils lightly. Attention to detail is paramount in achieving cleanliness levels that produce large improvements in machine life and availability. When it comes to machine life, lubricant cleanup has proven to be one of the simpler and more cost-effective methods of achieving measurable improvement. Don't wait for contaminants to destroy your machines. Clean up your oil and keep it clean!

## References


1. Toms, Larry A., *Machinery Oil Analysis, 2nd Edition*, Coastal Skills Training, Virginia Beach, Virginia.
2. Fitch, J. C., *Oil Analysis Course Manual*, Noria Corporation, Tulsa, Oklahoma.
3. *A Guide to Standards for Contamination Specifications in Liquids*, Pacific Scientific Instruments, HIAC Royco Division.
4. *ISO/FDIS 4406:1999(E)*, International Standards Organization.
5. *Industrial Oils*, Chevron USA, Incorporated.
6. *The Handbook of Hydraulic Filtration*, Parker Hannifin Corporation, Parker Filtration Division.
7. *Machine Design,* "How Dirt and Water [Affect] Bearing Life," Timken Bearing Company.